

The status and prospect of mining technology in Vietnam underground coal mines

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Abstract. Vietnam has the 13th largest hard coal reserves globally, with the reserves totaling 2.22 billion tonnes, and estimated resources of 4.07 billion tonnes. Coal use is playing an increasing role in the energy mix and according to current planning, this role is to increase further. In parallel with the development of the Vietnamese coal sector, underground mining also underwent many stages of improvements, especially in the last two decades. This paper analyzes the achievement and the state of the mining technology applied into the underground mining by the Vietnam National Coal - Mineral Industries Holding Corporation Ltd. (VINACOMIN) during 20 year period and proposes the recommendations for the sustainable development of Vietnam underground mining.

1. Introduction

Vietnam has large anthracite resources, with the largest coalfield being located in the Quangninh province. Quangninh coalfield is located in the northeastern part of the country, with 120 km length and 10-30 km width. The most recent update of the master plan for coal development (Master Plan of Coal Industry Development in Viet Nam by 2020, with perspective to 2030) estimates that Vietnam has almost 2.22 billion tonnes of hard coal reserves and almost 4.07 billion tons of resources, in which the measured and indicated resources (categories A+B+C1) occupy 35.3%, the inferred resource (C2) is 8%, and the prognostic resource (P) is 56,7% [1].

Coal extraction is run by the Viet Nam National Coal-Mineral Industries Holding Corporation Ltd. (VINACOMIN), a state-owned enterprise, which plays an important role in national strategies to ensure effective exploitation of mineral resources. VINACOMIN operates 3 main coal regions, i.e: Uongbi, Hongai, and Campha in which mining is carried out in 13 underground coal mines with production than 1.0 million tons per year. For instance, Uongbi region has Mao Khe (1.88 million tons/year), Nam Mau (2.21 million tons/year), Vang Danh (3.15 million tons/year) and Uong Bi (2.6 million tons/year). Hongai region has Nui Beo (2 million tons/year), Ha Lam (3.15 million tons/year) and Hon Gai (2.5 million tons/year). Campha region has Quang Hanh (1.7 million tons/year), Duong Huy (2.15 million tons/year), Thong Nhat (2.1 million tons/year), Khe Cham (1.8 million tons/year), Mong Duong (1.55 million tons/year) and Ha Long (2.15 million tons/year). Average exploitation depth of underground coal mines is 300m below sea level (the equivalent to the depth of 320-700m below the ground surface). Main underground coal mines in Quangninh coal basin is illustrated in Figure 1.

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Fig. 1. Main underground coal mines in Quangninh coal basin

In the last twenty years, coal output from the Vietnam underground coal mines increased rapidly from 4.3 million tonnes in 2000 to 22.1 million tonnes in 2018 (grew about 5 times). According to the Master Plan of Coal Industry Development in Viet Nam by 2020, with perspective to 2030, which was adjusted in 2016 [1], and mining plan of VINACOMIN total coal output will reach the level of 41 million tons in 2019, 47.8 million tons in 2020 and 49.3 million tons in 2025. In which, underground mining coal output will increase gradually year by year and will achieve the largest share (to 73%) in the total output of the overall coal industry in 2025. Details of coal production over the period between 2000 and 2018 with forecasts to 2025 are presented in Figure 2.

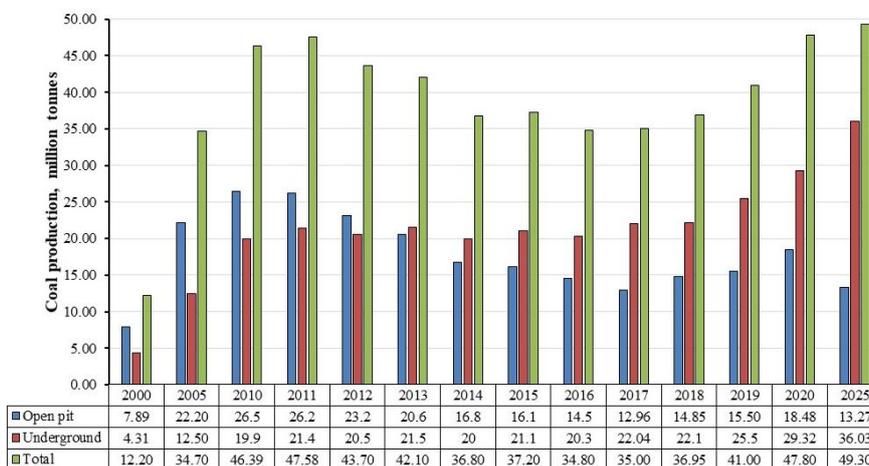


Fig. 2. Vietnamese coal production between 2000 and 2018 with forecasts to 2025 [2]

2. Analysis of geological conditions of coal in Quangninh area for underground mining

The application of mining technologies depends greatly on regional geological conditions. Based on data from coal companies [2], information obtained from previous studies [4,5] as well as the Master Plan of Coal Industry Development [1], coal reserves of 13 underground coal mines in Quangninh has been analyzed and evaluated. The results have identified the correlation between geo-mining conditions to the selection of mining technology in Vietnam.

Results from the abovementioned analysis showed that total coal reserves investigated to a depth -600m below the sea level is 1,609,767 thousand tonnes, in which, coal reserves are mainly distributed in the thickness between 3.5 and 10.0 meters with 44.1% and 22.5% of coal reserves have a thickness between 2.2 and 3.5 meters. In addition, 60% of coal reserves have the incline seam dip (from 150 to 350). In addition, a large part of these reserves are located in areas of difficult geological conditions, for example, structural disturbance, dipping seams, complicated surrounding strata, and coal seams are separated by faults that may restrain mining productions. The variation of seam dip and seam thickness is high, causing difficulty in the application of the mechanized mining technologies. So that over the years, underground mining in Vietnam faced many challenges in the extraction of coal seams. The summary of coal reserves at some deposits in Quangninh coalfield is presented in Table 1.

Table 1. Coal reserves by region in 1000 tons

No.	Name of coal mine	Evaluated level (compared to sea level)	Coal reserves, 10 ³ tons
1	Vang Danh	to -350m	230,337
2	Mao Khe	to -400m	142,140
3	Uong Bi	to -300m	136,207
4	Nam Mau	to -250m	166,149
5	Nui Beo	to -450m	55,931
6	Ha Lam	to -450m	143,541
7	Hon Gai	to -600m	202,967
8	Quang Hanh	to -300m	48,785
9	Thong Nhat	to -350m	51,984
10	Mong Duong	to -550m	68,854
11	Khe Cham	to -350m	80,083
12	Duong Huy	to -250m	79,914
13	Ha Long	to -400m	202,875
	Total		1,609,767

3. Status of underground mining technology in Quangninh coalfield

Underground coal mining has been operating in Vietnam for many years [6]. Coal reserves in the Quangninh area were extracted by French colonialist companies from 1884 to 1955 with total production more than 50 million tons. When the Vietnamese government took control of the country, the state-owned coal companies started renovating the old

mining collieries acquired from the French and also constructed new mines with the aim of increasing the production of coal in Quangninh to 10 million tonnes in 1980. However, due to both the complications of geo-mining conditions and poor mining equipment, coal production remained at 4 to 6 million tonnes per year for many years. The establishment of VINACOMIN in 1994 can be considered a new period in the history of the development of Vietnam's coal industry-the period of innovation in management, production and business activities. This has resulted in a visible increase in coal production in the last twenty years.

In Quangninh coalfield, underground mines have applied various types of mining technologies suited to the geological characteristics. For example: (1) the longwall mining method, exploiting the full seam thickness, applied for the medium thickness seam, dipping up to 35°; (2) longwall top coal caving (LTCC) applied for thick coal seam, dipping up to 35°; (3) the mining method, retreats along the seam dip, applied to steep seam, medium thickness; (4) the diagonal longwall system using hydraulic support model ZRY for average thick seams up to 4.5m, dip above 45°; (5) the sub-level mining method applied for slope seams; (6) the shortwall mining technology using hydraulic support or shield support applied for the steep thick seams. In which, coal seams in the Quangninh area were almost extracted by a single pass longwall method.

It is understood that a proper selection of the equipment synchronization in longwall is one of the key element for a successful operation of the mining technology. Underground mining companies have been struggling to find the most suitable equipment for the extraction of coal seams by longwall methods. Initially, most of the longwall faces were supported by wooden props (Figure 3a), while coal was extracted from the face by the drilling and blasting method. Due to the improvement in coal production, productivity, and the standards of mine safety, VINACOMIN applied hydraulic single props (Figure 3b) since 1997 and semi-mechanized shields model XDY-1T2/LY (Figure 3c and Figure 4a) since 1999. The success of these works has created a "technical revolution" to hydraulically replace the wooden props and improved the overall technical economical parameters. Coal production in the longwall faces supported by hydraulic support has increased rapidly from 100,000 to 150,000 tonnes per year as compared with the production of 50,000-70,000 tonnes per year when the face was supported by wooden props [3]. Coal mining productivity using the hydraulic single props increased to 2.5-5.37 tonnes per man-shift, an average of 3.0-3.5 tonnes per man-shift.

Since 2006, VINACOMIN has continued to apply new hydraulic supports in the underground coal mines, for instance, self-moving hydraulic frame model ZH1600/16/24Z (Figure 4b), model GK/1600/16/24/HTD (Figure 4c) and model ZH1800/16/24ZL. Production increased range from 140,000 to 250,000 tonnes per year, labor productivity from 5.0-7.0 tonnes per man-shift [3]. In addition, working conditions and safety on workplaces has been significantly improved. Mining began more environmentally friendly due to the elimination of wooden support. However, mining operations also required the amount of manual work, and this type of supports are only suitable for extraction by the drilling and blasting. As a result, production is still limited. Therefore, the increase of coal mining production according to the VINACOMIN's plan, which means an increase in the number of longwalls as well as the number of workers. This is hardly feasible in the current mining situation in Vietnam. This is the opening step for the renovation of underground mining technology, which is a premise for the introduction of mechanized equipment into underground mines in Quangninh coalfield.

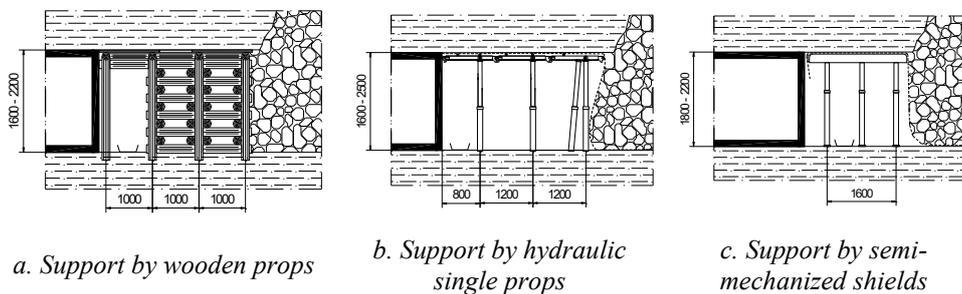


Fig. 3. The longwall face supported by wooden props and hydraulic props



Fig. 4. The longwall face supported by semi-mechanized shields

In 2002, Khe Cham Coal Mine firstly applied the longwall mining method, face supported by self-moving hydraulic beam XDY-JF/LR/T2/120JZ, exploiting the full seam thickness by shearer model MG-200 W1 at the seam No.14.4, level of -10/+32. During the trial period (from April 2002 to September 2005) the longwall exploited 512,918 tons of coal. The highest monthly exploitation output reached 22,300 tons, and the average labor productivity was 5.16 tonnes per man-shift. Based on the results achieved by the first semi-mechanized longwall, in 2005, Khe Cham Coal Mine has continued applying the first mechanized mining technology (Figure 5) in the similar condition, using shield support ZZ-3200/16/26 combined with the shearer MG150/375-W. The mechanized longwall has a high output of 233-388 thousand tons/year, averaging 289 thousand tons/year; labor productivity from 9.9-11.4 tons/per man shift, an average of 10.3 tons per man shift [3]. The success of the longwall was also a premise for technological innovations in the next exploitation for medium thick seams in Duong Huy and Quang Hanh coal mine since 2015. Compared with the longwall supported by hydraulic support in the same conditions, the average output of the mechanized longwall is 2.3-3.9 times higher, and the average productivity is 2.5-3.0 times higher.



Fig. 5. The mechanized longwall in Khe Cham coal mine [5]

Some mines have investigated the mechanized mining equipment for the extraction of thick and gentle slope seams. For example, in November 2007, Vang Danh coal mine applied the LTCC (Figure 6a), supported by mechanized equipment i.e. shield VINAALTA-2.0/3.15, shearer, Armoured Face Conveyor (AFC) and chain conveyor. As a result, the highest production reported approximately 450,000 tonnes/year. This mining mechanization technology was expanded to Nam Mau coal mine where was applied in 2010 [3]. In the period from 2015 to now, VINACOMIN has applied new LTCC method using double AFC (front conveyor and rear conveyor (Figure 6b), in which, the relocation of the top coal draw process to the rear conveyor) in 3 underground mines. There are longwalls in Ha Lam coal mine (one LTCC capacity of 600,000 tons/year since March 2015, one LTCC having capacity of 1,200,000 tons/year since November 2016), Khe Cham coal mine since April 2016 (capacity of 600,000 tons/year) and in Vang Danh coal mine since November 2018 (with capacity 450,000 tons/year). Labor productivity is relatively high with an average of 33.5-34.0 tons per man-shift, and 4-5 times higher than longwall using semi-mechanized support.

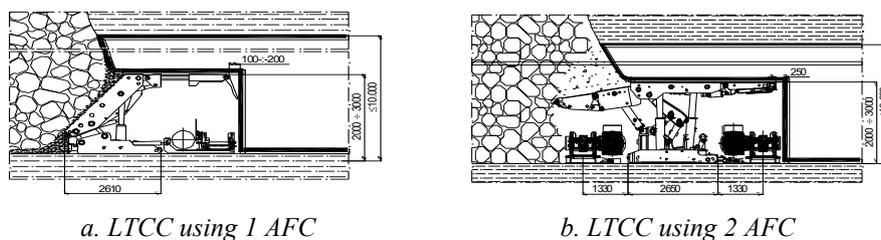


Fig. 6. The mechanized longwall method applied for the thick and gentle slope seams [5]

In the steep thick seams, in the period of 2007-2013, Vang Danh and Ha Long coal mines have put into the trial application of shortwall technology, face supported by power shield model KDT-1, KDT-2, and top coal caving by blasting drilling in the long hole. But both of the above works have not reached the set objectives. The main reasons for this are seen in the complex geology conditions (water flowing into the shortwall, fluctuation of seams, large mine pressure).

The mechanization technology retreats along with the seam dip, extracting the high steep thin coal seams by coal plough has been applied since 2008 in Mao Khe and Hong Thai coal mine, supporting by shield support 2ANSHA. Labour capacity and productivity of coal mining mechanized longwall by self-acting shield support 2ANSHA (average

mining capacity is 64.500 tons/year, labour productivity reached 5.6 tonnes per man-shift) was two times higher, the expense for preparation roadway was seven times lower and technology loss (16%) decreased two times than sublevel mining technology, supported by a movable hydraulic beam in the same geological conditions [3]. In addition, since August 2015, Hong Thai coal company (now belong of Uong Bi coal mine) has applied the new diagonal longwall system using hydraulic support model ZRY at seam No.9B, level of +30/+95. By the end of 2015, technology has achieved relatively great results: average coal output of 400 tons/day, labor productivity reached 5.5-6.0 tonnes per man-shift (2-3 times higher compared with sublevel mining method); and coal loss only between 12.6-16.3% [3] [3]. This technology has improved the level of safety and working conditions. More importantly, the application of the diagonal longwall system with the use of support ZRY has reduced the rate of roadway development per tonne of coal production, with only 16,7 metres per 1000 tonnes as compared with average 30-40 metres per 1000 tonnes in the sub-level mining method. Thereby, the experimental project in Hong Thai opened a new way to innovate the mining technology for steep seams. Up to now, VINACOMIN has 6 underground mines applying the mining technology with 7 longwalls.

The results of analyzing the status of underground mining show that, before 1998, underground coal production was only 4,186 thousand tons and coal output mainly from longwalls using wooden props. With the strong innovation of mining technology after 1998, rate of coal production from longwalls using wooden props decreased to 60.1% in 2001, only 9.0% in 2005 and less than 1% in 2018, while coal output from longwalls using hydraulic support increased from 22% in 2001 to 63-64% in the period 2005-2018. In addition, the rate of coal exploited by mechanized technologies has increased rapidly, for example, in 2018 reached 15% of total underground coal output, equal to 5 times compared to 2010 (3%) and equal to 7.5 times compared to 2005 (2%). Underground coal production of VINACOMIN according to mining technology as illustrated in Figure 8.

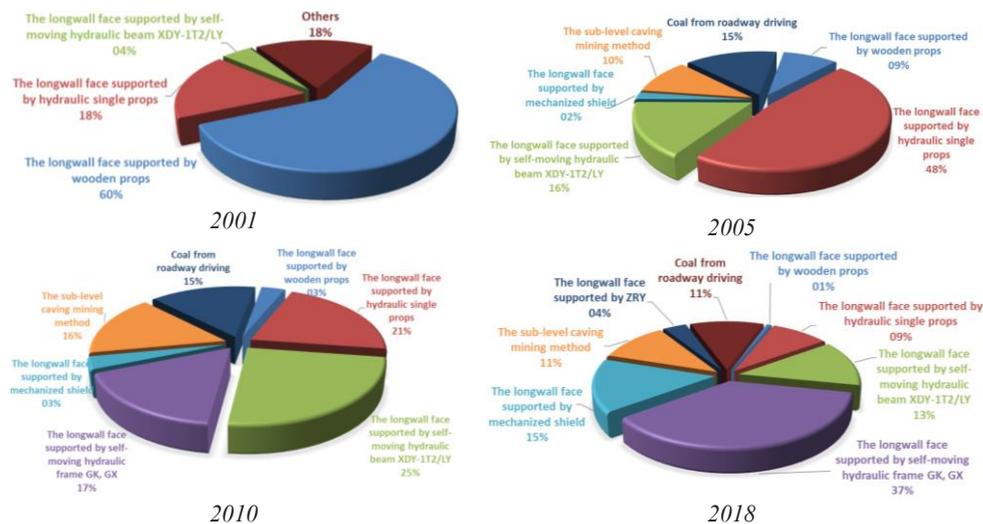


Fig. 8. Underground coal production of VINACOMIN according to mining technologies [2]

4. Prospect of Underground Mining Technology in Vietnam

According to the Master Plan No. 403 [1] and to the 5-year plan of 2019-2023 [3] the total coal output of VINACOMIN will increase for high demand of the national industry, while labor recruitment (especially labor for underground mines) is increasingly difficult. VINACOMIN is actively implementing a number of tasks: (1) Promote application of mechanization, automation, computerization and new advanced technologies into production; (2) Increasing output to reach mine capacity of invested projects; (3) Increase labor productivity, reduce production costs, ensure business efficiency and sustainable development; (4) Improve workplace safety, working conditions, increase income for workers; (5) Reach the objectives for 2020-2023, i.e. reach over 25% of total coal mining capacity by coal production from longwall applying fully mechanized mining technology.

From the actual experience, some main reasons affecting the efficiency of mining technologies application work at underground mines in Quangninh coalfield can be defined as follows:

1. Continue to expand the application of different types of technologies that have successfully implemented in the underground coal mines in Quangninh coalfield for areas with suitable conditions such as:
 - Synchronous mechanization technology to exploit seams with thickness, seam dip up α to 35° (most effective when $\alpha \leq 25^\circ$, similar types of 2 AFC in Ha Lam and Vang Danh) at Nui Beo and Khe Cham II-IV mines (reserves has been planned according to mine construction projects);
 - Mechanized mining technology for medium thick seams, slope up to 35° ;
 - Applying the diagonal longwall system using hydraulic support model ZRY for companies with average thick seams up to 4.5m, dip above 45° such as Vang Danh, Quang Hanh, Uong Bi, Ha Long and Hon Gai
2. Develop and apply mechanized mining technologies using lightweight self-support with suitable conditions in Mong Duong, Nam Mau, Ha Lam, Khe Cham II-IV and Uong Bi coal mines;
3. Studying and applying experimental technical and technological solutions to mining in medium thick seam conditions, slope angle to 45° , seams with "3 soft conditions" (soft coal, roof and floor) at Mao Khe, Uong Bi coal mines.
4. Researching and applying experimental mining technology in thick, steep and suitable reservoir conditions at Vang Danh, Ha Lam, and Nam Mau coal mines.
5. Study and apply the diagonal longwall system using hydraulic support model ZRY replicate mining technology sublevel caving in conditions of steep seams.
6. Viewpoints if high-capacity mechanized complexes cannot be applied such as Ha Lam, Vang Danh, and Khe Cham coal companies. Coal mines must actively coordinate with the consulting company to invite foreign experts to carefully survey geological conditions, suitable application conditions to order and design mechanized complexes suitable to application conditions with capacity from 250,000-350,000 tons per year.

5. Summary

A critical review of the current level of underground coal mining in the Quangninh coalfield showed that over the last 20 years, technology and management have been improved. These improvements resulted in a visible increase in coal production from 9.4 million tonnes in 1994 to nearly 40 million in 2018, in which, coal output from the underground coal mines increased rapidly from 4.3 million tonnes in 2000 to 22.1 million tonnes in 2018 (grew about 5 times). However, this improvement was still limited in

capacity and safety management. The increase in total coal production was mainly based on the increase in the number of longwall faces. In addition, the maximum output of the longwall face is low compared to the longwall faces in developed countries. The main reason for the limits in coal production and safety management is the inappropriate mining equipment used. Mining operations require a number of processes to be undertaken by manual work, resulting in low production and productivity.

In the coming years, the Vietnamese economy's demand for coal product will increase rapidly and this requires an improvement in the mining industry. Unfortunately, open-pit mining will be gradually scaled down and will end in 2030. As a result, there is a need to improve the underground mining sector. In order to ultimately prevent potential problems and realize the potential revenue in the underground coal mines, it is necessary to improve the understanding of the operational issues associated with the application of mechanized mining equipment suitable with conditions of the Quangninh coalfield.

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